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Effect of Prior Freezing on Dehydration and Rehydration of Apple Half Segments

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SUMMARY

York Imperial apples were peeled, cored, sliced into half segments (32 pieces per apple), sulfite-dipped, screened and drained. They were then either frozen quickly by tumbling in shaved dry ice, frozen slowly by storing overnight at $-8°F$, or not frozen at all. Next, they were air dried at 165°F dry bulb temperature to about 23% moisture content for the first drying stage, and finally either air dried at 150°F dry bulb temperature or vacuum dried at 29 in. Hg and 190°F platen temperature for the second stage. Both rapid and slow freezing prior to drying resulted in improved rehydration. Second-stage drying method (hot air or vacuum) had no apparent effect on rehydration, but second-stage vacuum drying resulted in a shorter drying time. The combination of slow freezing and second-stage vacuum drying gave the shortest drying time.

INTRODUCTION

The simple act of freezing has for many years been recognized as having an effect on the physical response of many foods to subsequent operations. For instance, a frozen vegetable will cook in a shorter time than the fresh product (Gortner, *et al.,* 1948). In addition, the rate at which freezing is accomplished is said to be important in freeze-drying because it affects the rate of drying and the rate of rehydration of the dry product.

According to one author (Dalgleish, 1962) rapid freezing gives small ice crystals mainly inside cell walls, causing drying and rehydration to be slow. On the other hand, very slow freezing gives large crystals that rupture cell walls, leading to rapid drying but damage to the product. Other workers (Lusk, *et al.,* 1965; Goldblith, *et al.,* 1963) reported that slowly frozen shrimp took less time to freeze-dry and took up more water on rehydration than rapidly-frozen shrimp. Cooked potato half-dice subjected to controlled freezing and thawing before air drying were reported to rehydrate almost instantaneously (Harrington, *et al.,* 1951). The work reported here was undertaken to determine if freezing and/or rate of freezing prior to drying would influence the drying rate or rehydration property of apple half-segments dehydrated according to commercial practice.

EXPERIMENTAL METHODS

Prefreezing. York Imperial apples were peeled, cored, sliced into half-segments (32 pieces per apple), dipped for 2 min in ½% $NaHSO_3$ solution at 70°F, screened over a 5/16 in. slotted screen, and drained. The half-segments not marked for slow freezing were then stored overnight in plastic bags at 38°F.

Freezing. The half-segments were either frozen slowly, frozen quickly, or not frozen at all. Slow-freezing consisted of placing the drying tray containing the half-segments in a cold room maintained at −8°F and storing overnight (ca. 16 hr.). Quick-freezing was carried out by mixing equal weights of the half-segments and shaved dry ice and tumbling at 6 rpm for 10 min in an apparatus similar to the "Thermlfreeze" unit (Anon., 1966).

Drying. Apples are dried commercially in two stages by at least one processor. In the first stage the dry-bulb temperature is maintained at or below 165°F until the product reaches 23% moisture. The second stage is carried out either with low humidity air at a dry-bulb temperature of 150°F or below, or in a vacuum shelf drier operating at 29 in. Hg with the platens at about 190°F. In the work reported here, these drying cycles were simulated in seven drying runs. In addition, one batch of half-segments was freeze-dried to provide a product for comparison with the others.

For the first six runs, first-stage drying was carried out in an experimental through-circulation air drier (Sinnamon, *et al.*, 1968). Dry-bulb temperature was 165°F, air rate was 150 SCFM (standard cubic feet per minute—volume referred to 60°F and one atmos. total press.), and relative humidity was 2%. For experiments in which freezing preceded drying, the half-segments were introduced to the drier in the frozen state.

Table 1. Results from rehydration tests.

Run No.	Freezing method	2nd stage drying	Rehydration ratios 1 min.	3 min.	5 min.
1	None	Air.	2.3	2.8	3.0
2	None	Vac.	2.3	2.9	3.1
3	Quick	Air	2.1	3.3	3.8
4	Quick	Vac.	2.8	4.2	4.7
5	Slow	Air	2.5	3.7	4.4
6	Slow	Vac.	2.5	3.8	4.1
7	Slow	Vac.	2.4	3.4	4.2
Confidence limits ($p = 0.05$)			± 0.61	± 0.86	± 0.30

Where second-stage air drying was used, it was carried out in the same experimental unit. Dry-bulb temperature was 150°F, air rate was 150 SCFM, and relative humidity was 2%. Where second-stage vacuum drying was used, it was done in a Stokes Model 902001 experimental freeze-drier with air bleeding into the chamber to maintain the vacuum at 29 in. Hg, and with the platen temperature maintained at about 190°F. The freeze-dried batch was dried in the same drier without an air bleed.

These two experimental driers have only one square foot each of tray area. Therefore, in order to obtain a larger batch of product, first-stage drying for run number 7 was carried out in a National Type TY1 through-circulation air drier with tray area of 6¼ square feet, and second-stage drying was done in a Stokes Model 338F vacuum shelf drier with tray area of 11½ square feet.

Product evaluation. Rehydration ratio, defined as the ratio of rehydrated weight to dry weight, was determined by simmering 40 g of the dry product in 2 cups (16 oz.) of water for 1, 3, or 5 min, straining off the water for 1 min, and weighing the rehydrated half-segments in a jar with lid.

Moisture content was determined on the dry product by loss of weight after 6 hr in a vacuum oven at 84°C. Moisture content of initial and intermediate products was calculated from the analysis of the dry product and the weight loss during the drying operation.

Sulfite content was determined by a published method (Nury, *et al.*, 1959) which has been modified at this laboratory.

RESULTS AND DISCUSSION

The results of the rehydration tests are given in Table 1 and plotted in Fig. 1. They show that with rehydration ratio as the criterion, freezing prior to drying resulted in more rapid rehydration of the pieces. Even without calculating rehydration ratio, however, it was evident at the end of the rehydration test that the half-segments frozen prior to drying were superior to

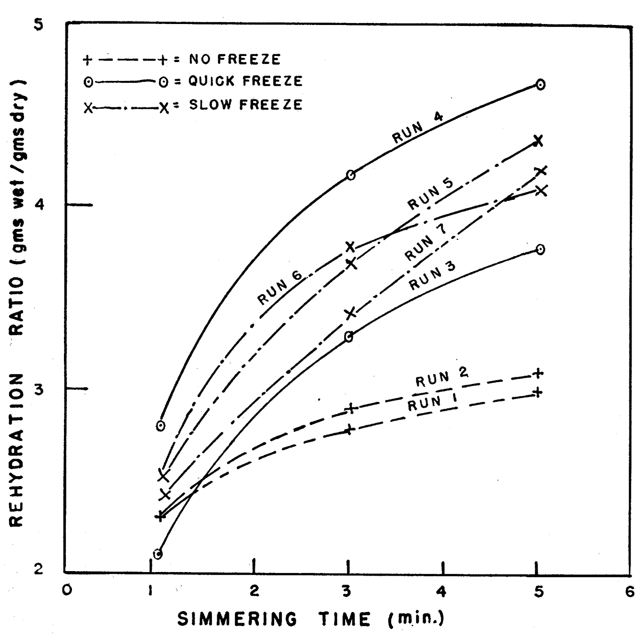

Fig. 1. Rehydration ratio curves for apple half-segments.

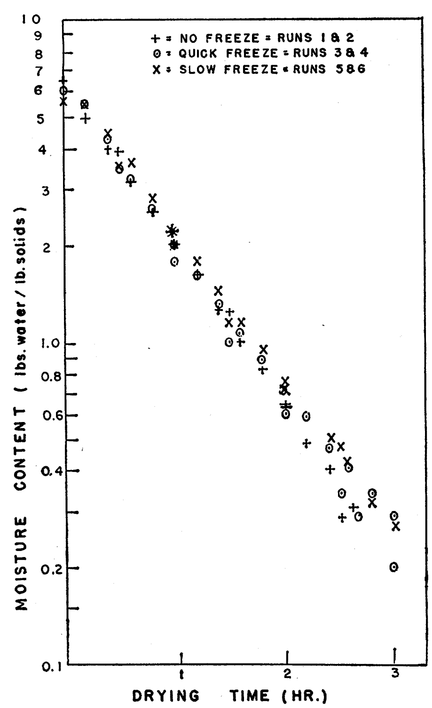

Fig. 2. First-stage drying of apple half-segments.

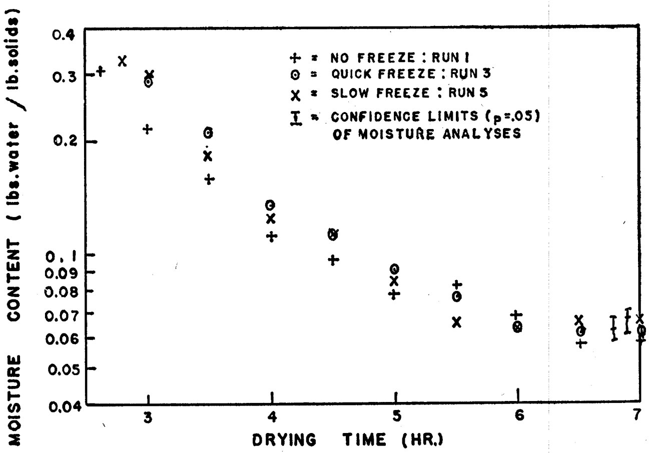

Fig. 3. Second-stage air drying of apple half-segments.

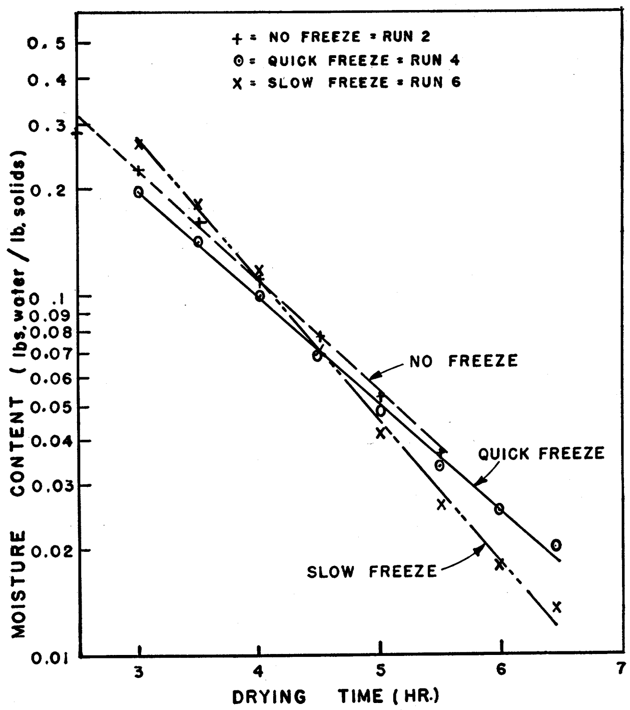

Fig. 4. Second-stage vacuum drying of apple half-segments.

the others. All frozen segments had fully regained their fresh shape after 5 min and were of good texture throughout, whereas those pieces not frozen were still partly shriveled at the end of 5 min and had tough centers. There was no apparent effect on rehydration due to the method of freezing. For comparison, the freeze-dried half segments, which rehydrated very well, had a rehydration ratio of 5.4 after 5 min.

The drying experiments are summarized in Table 2, and drying curves are given in Figs. 2 through 4. They show that the pieces that were not frozen completed first-stage drying before the others. This was undoubtedly caused by the fact that the other pieces were frozen when drying commenced.

Second-stage air drying was not completed because the moisture content was not reduced to 3½% or less. However, it would appear that the rate of second stage air drying was not affected by freezing. The rate of second-stage vacuum drying, however, was increased very significantly by slow freezing. Regression lines were fitted to the three sets of data as shown in Fig. 4. F-tests showed that the regression lines fit the respective data points very well, and confidence limits calculated for the slopes of the three lines showed a highly significant difference between the slope of the "slow freeze" line and slopes of the other lines. No significant difference in slopes was found between the "quick freeze" and the "no freeze" lines.

This work has shown that by merely freezing York Imperial apple half-segments prior to drying, the rehydration characteristic of the dry product is improved markedly, regardless of whether second-stage drying is done in air or under vacuum. In addition, "slow freezing" prior to drying increases the rate of second-stage vacuum drying.

This work also suggests that the technique of freezing prior to drying can be applied advantageously to other commodities, such as potatoes, carrots, beets, etc. Exploratory experiments with such commodities are now being conducted.

Table 2. Summary of drying experiments.

Run number	1	2	3	4	5	6	7
Moisture (%)	86.2	86.8	85.9	85.7	86.4	85.1	85.5
Sulfite (ppm, MFB[1])	1900	2500	2100	1800	1200	1300	1900
Freezing method	None	None	Quick	Quick	Slow	Slow	Slow
1st stage drying:							
Dry bulb temp (°F)	165	165	165	165	165	165	165
Tray loading (lb. fresh/ft²)	10.0	10.0	10.0	10.0	10.0	10.0	13.2
Drying method	Air	Air	Air	Air	Air	Air	Air
Drying time (hr.)	2.6	2.5	3.0	3.0	2.8	3.0	2.0
Final moisture (%)	23.6	22.3	22.1	16.6	24.4	21.2	25.9
2nd stage drying:							
Dry bulb or platen temp (°F)	150	192	150	190	150	192	190
Tray loading (lb. fresh/ft²)	10.0	7.6	10.0	8.3	10.0	7.5	7.1
Drying method	Air	Vac.	Air	Vac.	Air	Vac.	Vac.
Drying time (hr.)	4.4	3.0	4.0	3.5	4.2	3.5	5.0
Final moisture (%)	5.8	3.6	6.0	2.0	6.2	1.4	2.2
Sulfite (ppm, MFB[1])	370	250	200	260	210	220	150

[1] "Moisture-Free Basis": Results adjusted to a common basis of 0% moisture content of the sample.

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Reference to certain products or companies does not imply an endorsement by the Department over others not mentioned.

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